Part V
Ensuring Long-Term Protection

Chapter 10
Taking Corrective Action

Contents

Taking Corrective Action

This chapter will help you:

- *Monitor the performance of a waste management unit and take appropriate steps to remediate any contamination associated with its operation.*
- *Locate and characterize the source of any contamination.*
- *Identify and evaluate potential corrective measures.*
- *Select and implement corrective measures to achieve attainment of the established cleanup standard.*
- *Work closely with the state and community representatives.*

Effective operation of a waste management unit involves checking the performance of the waste management system components. When components are not operating effectively or when a problem develops, corrective action might be needed to protect human health and the environment. Corrective action involves identifying exposure pathways of concern, selecting the best corrective measure to achieve the appropriate cleanup standard, and consulting with state and community representatives.

> This chapter will help address the following questions.
>
> - What steps are associated with corrective action?
> - What information should be collected during investigations?
> - What factors should be considered in selecting an appropriate corrective measure?
> - What is involved in implementing the selected remedy?

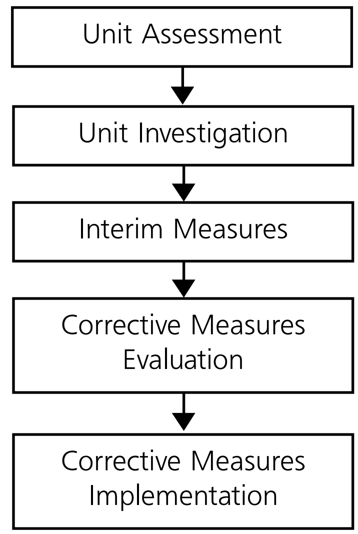
I. Corrective Action Process

The purpose of a corrective action program is to assess the nature and extent of the releases of waste or constituents from the waste management unit(s); to evaluate unit characteristics; and to identify, evaluate, and implement appropriate corrective measures to protect human health and the environment. The overall goal of any corrective action should be to achieve a technically and economically feasible cleanup standard at a specified point on the facility property. For new facilities this point should be on facility property, no more than 150 meters from the waste management unit boundary (as established in Chapter 9–Monitoring Performance). Existing facilities can either use this same 150 meter monitoring point standard or work with their state agencies to determine an alternate set of acceptable monitoring and cleanup criteria. Using the ground-water pathway as an example, the corrective action goal should be to reduce constituent concentration levels to the applicable maximum contaminant levels (MCLs) or health based numbers at the monitoring point (i.e., for new units, no more than 150 meters from the waste management unit).

A corrective action program generally has the components outlined here and in Figure 1 (and explained in greater detail below). The detail required in each of these components varies depending on the unit and its complexity and only those tasks appropriate for your site should be conducted. We recommend that you coordinate with the state during all phases of corrective action.

- Perform a unit assessment to locate the actual or potential source(s) of the release(s) of contaminants based on waste management unit monitoring information and the use of other existing information.
- Perform a unit investigation to characterize the nature and extent of contamination from the unit and any contamination that might be migrating beyond the facility boundary, identify areas and populations threatened by releases from the unit, and determine short- and long-term threats of releases from the unit to human health and the environment.
- Identify, evaluate, and implement interim measures, if needed. Interim measures are short-term actions taken to protect human health and the environment while a unit assessment or a unit investigation is being performed or before a corrective measure is selected.
- Identify, evaluate, and implement corrective measures to abate the further spread of contaminants, control the source of contamination, and to remediate releases from the unit.
- Design a program to monitor the maintenance and performance of any interim or final corrective measures to ensure that human health and the environment are being protected.

Figure 1 Corrective Action Process



A. Unit Assessment

Often the first activity in the corrective action process is the unit assessment. A unit assessment identifies potential and actual releases from the unit and makes preliminary determinations about release pathways, the need for corrective action, and interim measures. If appropriate, evaluate the possibility of addressing multiple units as the corrective action process proceeds. Table 1 identifies a number of factors to consider during a unit assessment. Tables 2 and 3 present some useful properties and parameters that define chemical

Table 1
Factors To Consider in Conducting a Unit Assessment

Unit/Site Characteristics	Chemical Characteristics	Migration Pathways	Evidence of Release Potential	Exposure
Contamination Parameters – Concentrations – Depth and location of contamination Physical Parameters – Geology – Depth to ground water – Flow characteristics – Climate Historical Information – History of unit – Knowledge of waste generation practices	Type of waste placed in the unit Volatilization parameters Toxicological characteristics Physical and chemical properties Chemical class Soil sorption/ degradation parameters	Facility's geological setting Facility's hydrogeological setting Atmospheric conditions Topographic characteristics Manmade features (e.g., pipelines, underground utility lines)	Prior inspection reports Citizen complaints Monitoring data Visual evidence, such as discolored soil, seepage, discolored surface water or runoff Other physical evidence such as fish kills, worker illness, or odors Sampling data Offsite water wells	Proximity to affected population Proximity to sensitive environments Likelihood of migration to potential receptors

Table 2
Chemical Characteristics

Property/Parameter	Characteristics
Chemical properties	Density, viscosity
Chemical class	Acid, base, polar neutral, nonpolar neutral, inorganic
Chemical reactivity	Oxidation, reduction, hydrolysis, polymerization, precipitation, biotic/abiotic
Soil sorption parameters	Cation exchange capacity, anion exchange capacity, soil/water partition coefficient (K_d), octanol/water partition coefficient (K_{ow})
Soil degradation parameters	Half-life, intermediate products of degradation
Volatilization parameters	Henry's law constant, vapor pressure

Table 3
Site Characteristics

Parameter/Information	Characteristics
Contamination parameters	Concentration in soil, water, and subsurface gas; depth and location of contamination
Physical parameters	Permeability, particle size distribution, organic matter, geology, moisture content, flow characteristics, depth to ground water, pH, wind directions, climate
Historical information	History of the waste management unit, knowledge of waste generation processes, waste quantity

Additional information on performing unit assessments can be found in RCRA Facility Assessment Guidance (U.S. EPA, 1986).

and site characteristics that you should consider when characterizing your site and environmental setting.

A beginning step is to review available site information regarding unit characteristics, waste characteristics, contaminant migration pathways, evidence of release, and exposure potential. Much of this information should have been gathered in the site assessment (see Chapter 4–Considering the Site) and waste characterization phases (see Chapter 2–Characterizing Waste). Conducting a visual site inspection of the unit will re-affirm available information and enable you to note any visual evidence of releases. If necessary, perform sampling to confirm or disprove suspected releases before performing an extensive unit investigation.

B. Unit Investigation

A unit investigation is conducted after a release from the operating unit has been confirmed. The purpose of the investigation is to gather enough data to fully characterize the nature, extent, and rate of migration of contaminants to determine and support the selection of the appropriate response action. It is important to tailor unit investigations to specific conditions and circumstances at the unit and focus on releases and potential pathways. Although each medium will require specific data and methodologies to investigate a release, a general strategy for this investigation, consisting of two elements, can be described as follows.

- Collect and review monitoring data, data which can be gathered from outside information sources on parameters affecting the release, or new information such as aerial photography or waste characterization.
- Formulate and implement field investigations and sampling and analysis or monitoring procedures designed to verify suspected releases. Evaluate the nature, extent, and rate of migration of verified releases. Refer to Chapter 9–Monitoring Performance to help design a monitoring program.

Detailed knowledge of source characteristics is valuable in identifying constituents for which to monitor, indicator parameters, and

Guidance on Performing Unit Investigations

Additional guidance on performing unit inspections can be found in the following EPA documents:

- *RCRA Facility Investigation Guidance Volume I: Development of an RFI Work Plan and General Considerations for RCRA Facility Investigations* (U.S. EPA, 1989a)
- *RCRA Facility Investigation Guidance Volume II: Soil, Ground Water, and Subsurface Gas Releases* (U.S. EPA, 1989b)
- *RCRA Facility Investigation Guidance Volume III: Air and Surface Water Releases* (U.S. EPA, 1989c)
- *RCRA Facility Investigation Guidance Volume IV: Case Study Examples* (U.S. EPA, 1989d)
- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (U.S. EPA, 1988a)
- *Draft Practical Guide for Assessing and Remediating Contaminated Sites* (U.S. EPA, 1989f)
- *Site Characterization for Subsurface Remediation* (U.S. EPA, 1991c)

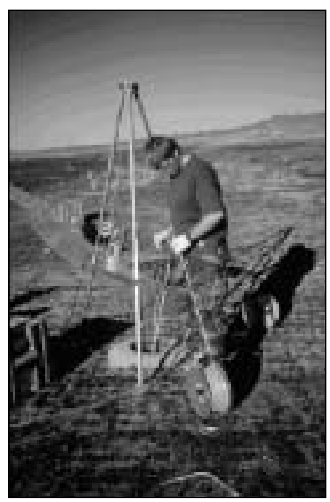
possible release pathways. It is also helpful in linking releases to a particular unit. Monitoring information collected by a program described in Chapter 9–Monitoring Performance can be helpful. Waste and unit characteristics can also provide information for determining release rates and for determining the nature and scope of any corrective measures which might be applied. Refer to Chapter 2–Characterizing Waste for information on how to characterize a waste.

Unit investigations can result in significant amounts of data, including the results of chemical, physical, or biological analyses. This can involve analyses of many constituents, in different media, at various sampling locations, and at different times. Data management procedures should be established to effectively process these data such that relevant data descriptions, such as sample numbers, locations, procedures, and methods, are readily accessible and accurately maintained.

1. *Specific Considerations for Ground-Water Investigations*

To facilitate ground-water investigations consider the following parameters:

- Ability of the waste to be dissolved or to appear as a distinct phase.
- Degradability of the waste and its decomposition products.
- Geologic and hydrologic factors which affect the release pathway.



- Regional and site-specific ground-water flow regimes that might affect the potential magnitude of the release pathways and possible exposure routes.

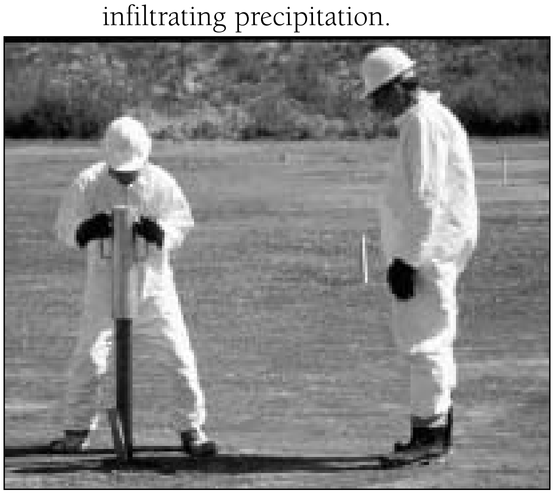
Exposure routes of concern include ingestion of ground water as drinking water and near-surface flow of contaminated ground water into basements of residences or other structures. It is important to also address the potential for the transfer of contaminants in ground water to other environmental media through processes such as discharge to surface water and volatilization to the atmosphere.

Use existing ground-water monitoring information, where it exists, to determine the nature, extent, and rate of contaminant release from the unit(s) to the ground water. Investigation of a suspected release might be terminated based on results from an initial monitoring phase if these results show that an actual release has not, in fact, occurred. If, however, contamination is found, you should characterize the release through subsequent monitoring to help determine the detailed constituent composition and concentrations, the horizontal and vertical extent of the contaminant release, as well as its rate of migration as appropriate to assess the risk. This should be accomplished through direct sampling and analysis and, when appropriate, can be supplemented by indirect means such as geophysical assessment and fate and transport modeling.

2. Specific Considerations for Soil Investigations

When performing soil investigations, consider the following parameters:

- Ability of the waste to be dissolved by infiltrating precipitation.



- The waste's affinity for soil particles.
- The waste's degradability and its decomposition products.
- Surface features such as topography, erosion potential, land-use potential, and vegetation.
- Stratigraphic/hydrologic features such as soil profile, particle-size distribution, hydraulic conductivity, pH, porosity, and cation exchange capacity.
- Meteorological factors such as temperature, precipitation, runoff, and evapotranspiration.

Relevant physical and chemical properties of the soil should be assessed to help determine potential mobility of any contaminants in the soil. Also, consider the potential for transfer of contaminants in the soil to other environmental media such as overland runoff to surface water, leaching to ground water, and volatilization to the atmosphere. In addition, you should establish whether a potential release involved a point source (localized) or a non-point source. Point sources might include container handling and storage areas, tanks, waste piles, and bulk chemical transfer areas. Non-point sources might include airborne particulate contamination originating from a land application unit and widespread leachate seeps from a landfill. Table 4 presents important mechanisms of contaminant release to soils for various unit types. This information can be used to identify areas for initial soil monitoring.

3. Specific Considerations for Surface-Water Investigations

When conducting surface-water investigations, the following factors should be considered:

- The release mechanism, such as overtopping of an impoundment.

Table 4
Potential Release Mechanisms for Various Unit Types

Unit Type	Release Mechanism
Surface impoundment	Releases from overtopping Leakage through dikes or unlined portions to surrounding soils
Landfill	Migration of releases outside the unit's runoff collection and containment system Seepage through underlying soils
Waste pile	Migration of releases outside the unit's runoff collection and containment system Seepage through underlying soils
Land application unit	Migration of runoff outside the application area Passage of leachate into the soil horizon

- The nature of the source area, such as point or non-point.
- Waste type and degradability.
- Local climate.
- Hydrologic factors such as stream flow conditions.
- The ability for a contaminant to accumulate in stream bottom sediments.

Also, address the potential for the transfer of contaminants in surface water to other environmental media such as soil contamination as a result of flooding of a contaminated creek on the facility property.

During the initial investigation, particular attention should be given to sampling runoff from contaminated areas, leachate seeps, and other similar sources of surface-water contamination, as these are the primary overland release pathways for surface water. Releases to surface water via ground-water discharge should be addressed as part of the ground-water investigation for greater efficiency. See Chapter 9–Monitoring Performance, Section II: Surface-Water Monitoring for information on proper surface-water monitoring techniques.

4. *Specific Consideration for Air-Release Investigations*

The intent of an air-release investigation is to determine any actual or potential effects at a nearby receptor. This might involve emission modeling to estimate unit-specific emission rates, air monitoring to determine concentrations at a nearby receptor, emission monitoring at the source to determine emission rates, and dispersion modeling to estimate concentrations at a nearby receptor. See Chapter 9–Monitoring Performance, Section IV: Air Monitoring for more information on air monitoring and Chapter 5–Protecting Air for more information on air modeling.

As in other media-specific investigations, the first step is to collect, review, and evaluate available waste, unit, environmental setting, and release data. Evaluation of these data can indicate the need for corrective measures or that no further action is required. For example, the source might involve a large, active storage surface impoundment containing volatile constituents adjacent to residential housing. Action, therefore, instead of further studies, might be appropriate. Another case might involve a unit in an isolated location, where an acceptable modeling or monitoring database indicates that the air release can be considered insignificant and, therefore, further studies are not warranted. In many cases, however, further release characterization might be necessary.

C. Interim Measures

Many cleanup programs recognize the need for interim measures while site characterization is underway or before a final remedy is selected. Typically, interim measures are used to control or abate ongoing risks before final remedy selection. Examples of interim measures for various types of waste management units and various release types are listed in Table 5. More information is available through the *RCRA Corrective Action Interim Measures Guidance—Interim Final* (U.S. EPA,

Table 5
Examples of Interim Corrective Measures

Unit/Release	Interim Measure
Containers	Overpack or redrum Construct storage area Move to new storage area Segregation Sampling and analysis Treatment or storage Temporary cover
Tanks	Construct overflow/secondary containment Leak detection or repair Partial or complete removal
Surface Impoundments	Reduce head Remove free liquids and highly mobile wastes Stabilize or repair side walls, dikes, or liner(s) Temporary cover Run-on or runoff control (diversion or collection devices) Sample and analyze to document the concentration of constituents Interim ground-water measures

Table 5
Examples of Interim Corrective Measures (cont.)

Unit/Release	Interim Measure
Landfills	Run-on or runoff control (diversion or collection devices) Reduce head on liner or leachate collection and removal system Inspect leachate collection and removal system, or french drain Repair leachate collection and removal system, or french drain Temporary cap Waste removal Interim ground-water measures
Waste Piles	Run-on or runoff control (diversion or collection devices) Temporary cover Waste removal Interim ground-water measures
Soils	Sampling or analysis Removal and disposal Run-on or runoff control (diversion or collection devices) Temporary cap or cover
Ground Water	Delineation or verification of gross contamination Sampling and analysis Interceptor trench, sump, or subsurface drain Pump-and-treat In situ treatment Temporary cap or cover
Surface-Water Releases (Point and Non-Point)	Overflow or underflow dams Filter fences Run-on or runoff control (diversion or collection devices) Regrading or revegetation Sample and analyze surface waters and sediments or point source discharges
Gas Mitigation Control	Barriers Collection Treatment Monitoring
Particulate Emissions	Truck wash (decontamination unit) Revegetation Application of dust suppressant
Other Actions	Fencing to prevent direct contact Sampling offsite areas Alternate water supply to replace contaminated drinking water Temporary relocation of exposed population Temporary or permanent injunction

1988b) and *RCRA Corrective Action Stabilization Technologies* (U.S. EPA, 1992b). Interim measures can be separate from the comprehensive corrective action plan, but should be consistent with and integrated into any longer term corrective measure. To the extent possible, interim measures should not seriously complicate the ultimate physical management of wastes or constituents, nor should they present or exacerbate a health or environmental threat.

D. Evaluating Potential Corrective Measures

The corrective measure or measures selected should meet the corrective action goals, such as a state or local cleanup standard, and control or remove the source of contamination to reduce or eliminate further releases. Most corrective measures fall into one of three technology categories—containment technologies, extraction or removal technologies, or treatment technologies. The performance objectives of the corrective measures relate to source reduction, cleanup goals, and cleanup timeframe. These measures might include the repair or upgrade of existing unit components, such as liner systems, leachate collection systems, or covers.

You should base selection of corrective measures on the following considerations and contact the state and community representatives before finalizing the selection:

- The ability to meet appropriate cleanup standards.
- The appropriateness and effectiveness of the treatment technology in relation to waste and site characteristics.
- The long- and short-term effectiveness including economic, technical feasibility, and protectiveness of the remedy.
- The effectiveness of the remedy in reducing further releases.
- The ease of implementing the remedy.
- The degree to which local community concerns have been addressed.

Potential Corrective Measures

Additional guidance on potential corrective measures is available from the following documents:

- *Corrective Action: Technologies and Applications* (U.S. EPA, 1989c)
- *Handbook: Stabilization Technologies for RCRA Corrective Actions* (U.S. EPA, 1991b)
- *RCRA Corrective Action Stabilization Technologies* (U.S. EPA, 1992b)
- *Pump-and-Treat Ground-Water Remediation: A Guide for Decision Makers and Practitioners* (U.S. EPA, 1996c)
- *Handbook: Remediation of Contaminated Sediments* (U.S. EPA, 1991a)
- *Abstracts of Remediation Case Studies* (U.S. EPA, 1995)
- *Bioremediation Resource Guide* (U.S. EPA, 1993)
- *Groundwater Treatment Technology Resource Guide* (U.S. EPA, 1994a)
- *Physical/Chemical Treatment Technology Resource Guide* (U.S. EPA, 1994b)
- *Soil Vapor Extraction Treatment Technology Resource Guide* (U.S. EPA, 1994d)

1. Meeting Cleanup Standards

Work with your state and community representatives to establish risk-based cleanup standards for the media of concern before identifying potential corrective measures. For example, if there is a statistically significant increase of constituent concentrations over background in the ground water, cleanup standards would include reducing contaminant concentrations to the MCL or health-based level at the point of monitoring.

Several approaches have been developed to identify appropriate cleanup standards. One of the more recent approaches is the Risk-Based Corrective Action (RBCA) standard developed by some states and the American Society for Testing and Materials (ASTM) Committee. The RBCA standard provides guidance on how to integrate ecological and human-health, risk-based, decision-making into the traditional corrective action process described above. RBCA is a decision-making process for the assessment and response to chemical releases. This standard is applicable to all types of chemical-release sites, which can vary greatly in terms of their complexity, physical and chemical characteristics, and the risk they pose to human health and the environment. RBCA uses a tiered approach that begins with simple analyses and moves to more complex evaluations when necessary. The foundation of the RBCA process is that technical policy decisions are identified in the front-end of the process to ensure that data collected are of sufficient quantity and quality to answer questions posed at each tier of the investigation. The RBCA standard is not intended to replace existing regulatory programs, but rather to provide an enhancement to these programs. The RBCA process allows for a three-tiered approach as described below.

In recent years, many states have adopted similar risk-based guidance or rules. The Louisiana Department of Environmental Quality, for instance, promulgated its Risk Evaluation/Corrective Action Program (RECAP) final rule, on June 20, 2000. Likewise, the Texas Natural Resource Conservation Commission (TNRCC) finalized the Texas Risk Reduction Program in 1999 (Title 30 Texas Administrative Code (TAC) Chapter 350). Your state and community representatives can tell you whether similar RBCA standards exist in your state and the appropriateness of such an approach. ASTM also offers two training courses on RBCA: Risk-Based Corrective Action for Chemical Releases, and Risk Based Corrective Action Applied at Petroleum Release Sites. These courses are open to all individuals from federal, state, tribal, and local regulatory agencies as well as professionals from the private sector.

RBCA Tier 1 Evaluation

A Tier 1 evaluation classifies a site according to the urgency for corrective action using broad measures of release and exposure. This tier is used to identify the source(s) of the chemical release, obvious environmental impacts, potential receptors, and significant exposure pathways. During a Tier 1 evaluation, site-specific contaminant concentrations are compared against a standard table of risk-based screening levels (RBSLs) that have been developed using conservative, nonsite-specific exposure assumptions. If a site's contaminant concentrations are found to be above the RBSLs, then corrective action or further evaluation would be considered. Continued monitoring might be the only requirement if site-specific contaminant concentrations are below the RBSLs.

At the end of the Tier 1 evaluation, initial corrective action responses are selected while additional analysis is conducted to determine final remedial action, if necessary. The standard includes an exposure scenario evaluation flowchart to help identify appropriate receptors and exposure scenarios based on current and projected reasonable land use scenarios, and appropriate response actions. Site conditions should also be compared to relevant ecological screening criteria (RESC) applicable to the site which might include qualitative or quantitative benchmarks, comparison of site conditions to local biological and environmental conditions, or considerations related to the exposed habitat areas.

RBCA Tier 2 Evaluation

The user might decide to conduct a Tier 2 evaluation after selecting and implementing the appropriate initial response action to the Tier 1 evaluation. The purpose of this tier is to determine site-specific target levels (SSTLs) and appropriate points of compliance when it is determined that Tier 1 RBSLs have been exceeded. While a Tier 2 evaluation is based on similar screening levels as those used in the Tier 1 evaluation, some of the generic assumptions used in the earlier evaluation are replaced with site-specific measurements to develop the SSTLs. The intent of Tier 2 is to incorporate the concept that measured levels of contamination can decline over the distance from source to receptor. Thus, simple environmental fate and transport modeling is used to predict attenuation over that distance. If site-specific contaminant concentrations are above the SSTLs, corrective action is needed and further analysis might be required.

RBCA Tier 3 Evaluation

A Tier 3 evaluation involves the same steps as those taken during the Tier 1 and Tier 2 evaluations, except that a significant increase in effort is employed to better define the scope of the contamination. Actual levels of contamination are compared to SSTLs that are developed for this Tier. The Tier 3 SSTLs differ from Tier 2 SSTLs in the level of sophistication used to develop site-specific measures of the fate and transport of contaminants. Where simplified, site-specific measures of the fate and transport are used in the Tier 2 evaluation, much more sophisticated models and data will be used in this Tier. These models might rely on probabilistic approaches and on alternative toxicity and biodegradability data.

2. Evaluating Treatment Technologies

In nearly every phase of the corrective action process, some information about treatment technologies is important. Many documents exist that describe candidate technologies in detail and give their respective applicability and limitations. Below are descriptions and examples of the three major technology categories: containment, extraction, and treatment.

Containment technologies are used to stop the further spread or migration of contaminants. Some examples of common containment techniques for constituents in land-based units include waste stabilization, solidification, and capping. Capping and other surface-water diversion techniques, for instance, can control infiltration of rainwater to the contaminated medium. Typical ways to contain contaminated ground-water plumes include ground-water pumping, subsurface drains, and barrier or slurry walls. These ground-water containment technologies control the migration of contaminants in the ground-water plume and prevent further dissolution of contaminants by water entering the unit.

- **Ground-water pumping.** Ground-water pumping can be used to manipulate and manage ground water for the purpose of removing, diverting, and containing a contaminated plume or for adjusting ground-water levels to prevent plume movement. For example, pumping systems consisting of a series of extraction wells located directly downgradient from a contaminated source can be used to collect the contaminated plume. The success of any contaminant capture system based upon pumping wells is dependent upon the rate of ground-water flow and the rate at which the well is pumped. Thus, the zone of capture for the pumping system must be established.

- **Subsurface drains.** Subsurface drains are essentially permeable barriers designed to intercept the ground-water flow. The water is collected at a low point and pumped or drained by gravity to the treatment system. Subsurface drains can also be used to isolate a waste disposal area by intercepting the flow of uncontaminated ground water before it enters into a contaminated site. Subsurface drains are most useful in preliminary containment applications for controlling pollutant migration, while a final treatment design is developed and implemented. They also provide a measure of long-term protection against residual contaminants following conclusion of treatment and site closure.
- **Barrier walls.** Low permeability barriers are used to direct the uncontaminated ground-water flow around a particular site or to prevent the contaminated material from migrating from the site. Barrier walls can be made of a wide variety of materials, as long as they have a lower permeability than the aquifer. Typical materials include mixtures of soil and bentonite, mixtures of cement and bentonite, or barriers of engineered materials (sheet piling). A chemical analysis of wall/contaminant compatibility is necessary for the final selection of materials. The installation of a low permeability barrier usually entails a great deal of earth moving, requires a significant amount of land area, and is expensive. Once in place, however, it represents a long-term, low maintenance system.

Extraction or removal technologies physically remove constituents from a site. Extraction techniques might remove the constituent of concern only, or the contaminated media itself. For example, vapor extraction might just remove the constituent vapors from the soil, while excavation could remove all of the contaminated soil. Extraction technologies

include excavation, pumping, product recovery, vapor extraction or recovery, and soil washing.

Treatment or destruction technologies render constituents less harmful through physical, biological, chemical, and thermal processes including ground-water treatment, pH adjustment, oxidation and reduction, bioremediation, and incineration.

- **Ground-water pump-and-treat** is one of the most widely used ground-water treatment technologies. Conventional methods involve pumping contaminated water to the surface for treatment. Pump-and-treat systems are used primarily for hydraulic containment and treatment to reduce the dissolved contaminant concentrations in ground water so that the aquifer complies with clean-up standards or the treated water withdrawn from the aquifer can be put to beneficial use. A thorough, three-dimensional characterization of subsurface soils and hydrogeology, including particle-size distribution, sorption characteristics, and hydraulic conductivity, provides a firm basis for appropriate placement of pump-and-treat wells. The following techniques can be useful in effectively designing and operating the pump-and-treat system:

- Using capture zone analysis, optimization modeling, and data obtained from monitoring the effects of initial extraction wells to identify the best locations for wells.
- Phasing the construction of extraction and monitoring wells so that information obtained from the operation of the initial wells informs decisions about siting subsequent wells.
- Phasing pumping rates and the operation of individual wells to enhance containment, avoid stagnation zones, and ensure removal of the most contaminated ground water first.

• **Chemical treatment** is a class of processes in which specific chemicals are added to wastes or to contaminated media in order to achieve detoxification. Depending on the nature of the contaminants, the chemical processes required might include pH adjustment, lysis, oxidation, reduction, or a combination of these. In addition, chemical treatment is often used to prepare for or facilitate the treatment of wastes by other technologies.

- The function of pH adjustment is to neutralize acids and bases and to promote the formation of precipitates, which can subsequently be removed by conventional settling techniques. Typically, pH adjustment is effective in treating inorganic or corrosive wastes.
- Oxidation and reduction reactions are utilized to change the chemical form of a hazardous material, in order to render it less toxic or to change its solubility, stability, separability, or otherwise change it for handling or disposal purposes. In any oxidation reaction, the oxidation state of one compound is raised (i.e., oxidized) while the oxidation state of another compound is lowered (i.e., reduced). In the reaction, the compound supplying the oxygen (or chlorine or other negative ion) is called the oxidizer or oxidizing agent, while the compound accepting the oxygen (i.e., supplying the positive ion) is called the reducing agent. The reaction can be enhanced by catalysis, electrolysis, or photolysis.
- The basic function of lysis processes is to split molecules to permit further treatment. Hydrolysis is a chemical reaction in which water reacts with another substance. In the reaction, the water molecule is ionized while the other compound

is split into ionic groups. Photolysis, another lysis process, breaks chemical bonds by irradiating a chemical with ultraviolet light. Catalysis uses a catalyst to achieve bond cleavage.

- **Biological treatment** is a destruction process relying primarily on oxidative or reductive mechanisms. The two types of biological treatment processes are aerobic and anaerobic. Aerobic processes are oxidative processes and are the most widely used. These processes require a supply of molecular oxygen and include suspended growth systems, fixed-film systems, hybrid reactors, and in situ application. Anaerobic processes achieve the reduction of organic matter to methane and carbon dioxide in an oxygen-free environment. The use of biological treatment processes is directed toward accomplishing destruction of organic contaminants, oxidation of organic chemicals whereby the organic chemicals are broken down into smaller constituents, and dehalogenation of organic chemicals by cleaving a chlorine atom(s) or other halogens from a compound.

  Biological processes can be used on a broad class of biodegradable organic contaminants. It should be noted, however, that very high concentrations as well as very low concentrations of organic contaminants are difficult to treat via biological processes. Since microorganisms need appropriate conditions in which to function, you must provide an optimum environment, whether aboveground in a reactor or belowground for an in situ application. The primary conditions which can affect the growth of the microbial community, in addition to providing them sufficient food (organic material), are pH, temperature, oxygen concentration, nutrients, and toxicity.

  - Typically, a biological treatment system operates best when a waste stream is at a pH near 7. However, waste treatment systems can operate (with some exceptions) between pH values of 4 and 10. The exceptions are aerobic systems in which ammonia is oxidized to NO_x as well as anaerobic methane fermenting systems. For these, the pH should be between 6 and 8; outside this range, efficiency will suffer.

  - Waste treatment systems can function over a temperature range of 5° to 60°C. Most waste treatment systems operate between 15° to 45°C and use mesophilic organisms.

  - Microorganisms need a certain amount of oxygen not only to survive but also to control their reactions. Therefore, the residual dissolved oxygen concentrations should be maintained at approximately 2 mg/l or greater within a typical liquid biotreatment system.

  - The quantity of nutrients needed depends on the biochemical oxygen demand (BOD) of the waste. The higher the BOD, the higher the number of cells produced and the greater the quantity of nutrients required.

  - The presence of toxic substances will obviously produce adverse conditions in a biological system. Unfortunately, it is difficult to cite specific toxic materials because toxicity depends on concentration. Nutrients can be toxic in higher concentrations and all types of organic compounds which can be used as food by bacteria can be toxic if their concentrations are high enough. Frequently, toxicity concerns can be avoided by waste dilution and microbe acclimation.

- **Thermal treatment**, or incineration, is a treatment technology applicable to the treatment of wastes containing a wide range of organic concentrations and low concentrations of water, metals, and other inorganics. Incineration is the thermal decomposition of organic constituents via cracking and oxidation reactions at high temperatures that can be used for detoxification, sterilization, volume reduction, energy recovery, and by-product chemical recovery. A well-designed and properly operated incinerator will destroy all but a tiny fraction of the organic compounds contained in the waste. Incinerator emission gases are composed primarily of carbon dioxide and water. The type and quantity of other compounds emitted depends on the composition of the wastes, the completeness of the combustion process, and the air pollution control equipment with which the incinerator is equipped. Incinerators are designed to accept wastes of varying physical forms, including gasses, liquids, sludges, and solids.
- **Stabilization/solidification** processes immobilize toxic or hazardous constituents in a waste by changing the constituent into immobile forms, binding them in an immobile matrix, or binding them in a matrix which minimizes the waste material surface exposed to solvent. Often, the immobilized product has a structural strength sufficient to prevent fracturing over time. Solidification accomplishes the intended objective by changing a non-solid waste material into a solid, monolithic structure that ideally will not permit liquids to percolate into or leach materials out of the mass. Stabilization, on the other hand, binds the hazardous constituents into an insoluble matrix or changes the hazardous constituent to an insoluble form. Other objectives of solidification/stabilization processes are to improve handling of the waste and produce a stable solid (no free liquid) for subsequent use as a construction material or for landfilling. Major categories of industrial waste solidification/stabilization systems are cement-based processes. Waste characteristics such as organic content, inorganic content, viscosity, and particle size distribution can affect the quality of the final solidified product. These characteristics inhibit the solidification process by affecting the compatibility of the binder and the waste, the completeness of encapsulation, and the development of preferential paths for leaching due to spurious debris in the waste matrix.

In selecting a treatment technology or set of technologies, it is important to consider the information obtained from the waste and site characterizations, see Chapter 2–Characterizing Waste and Chapter 4–Considering the Site. For example, the waste characterization should tell the location of the waste and in what phase(s) the waste should be expected to be found, (e.g., sorbed to soil particles). Waste characterization information also allows for the assessment of the leaching characteristics of the waste, its ability

1 U.S. EPA, 1991. *Site Characterization for Subsurface Remediations.*

to be degraded, and its tendency to react with chemicals. The site characterization information should reveal important information about subsurface flow conditions and other physical characteristics, such as organic carbon content. You should use the information from the waste and site characterizations to select the appropriate treatment technology.

A screening process for selecting an appropriate technology is presented in Figure 2. In some cases, a treatment train, a series of technologies combined together, might be appropriate.[1] This step-by-step approach helps ensure that technologies that might be applicable at a site are not overlooked. In addition, the rationale for the elimination of specific technologies will be available to justify decisions to interested parties.

Additional information regarding the use and development of innovative treatment technologies is available from EPA's Hazardous Waste Clean-up Information (CLU-IN) Web site <**clu-in.org**>. This Web site describes programs, organizations, publications, and other tools for all waste remediation stakeholders. Of particular interest is the Remediation Technologies Screening Matrix which is a user-friendly tool to screen for technologies for a remediation project. The matrix allows you to screen through 64 in situ and ex situ technologies for either soil or ground-water remediation. Variables used in screening include contaminants, development status, overall cost, and cleanup time. The matrix can be accessed through CLU-IN or directly from the Federal Remediation Technologies Roundtable's Web site <**www.frtr.gov/matrix2/top_page.html**>.

Another source of information is the Field Analytic Technologies Encyclopedia (FATE) developed by EPA's Technology Innovation Office (TIO), in collaboration with the U.S. Army Corps of Engineers. FATE is an online encyclopedia of information about technologies that can be used in the field to characterize contaminated soil and ground water, monitor the progress of remedial efforts, and in some cases, confirm sampling and analysis for site closure. To access FATE visit: <**www.epa.gov/tio/chartext_tech.htm**>.

Figure 2

Recommended Screening Process for Selecting Appropriate Treatment Technologies

Evaluate waste and site-specific information and identify potential treatment technologies

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Develop a conceptual design for each technology including:
- Process description
- Process flow diagram
- Layout drawing
- Preliminary sizing of equipment, utility, and land requirements
- Chemical requirements
- Expected residuals

↓

Compare technologies using:
- Effectiveness and reliability of technology meeting cleanup goals
- Beneficial and adverse effects on the environment
- Beneficial and adverse effects on human health
- Ability to meet federal, state, and local government standards and gain public acceptance
- Capital, operating, and maintenance costs

↓

Select most appropriate technology in consultation with state and community representatives

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Obtain state approval

3. *Evaluating the Long- and Short-Term Effectiveness of the Remedy*

Evaluating the long- and short-term effectiveness of the remedy, involves analyzing the risks associated with potential exposure pathways, estimates of potential exposure levels, and the duration of potential exposure associated with the construction and implementation of the corrective measure. Because waste characteristics vary from site to site, the effect of a treatment technology with a particular waste might be unknown. It is important, therefore, to consider performing a treatability study to evaluate the effectiveness of one or more potential remedies. Spending the time and money up-front to better assess the effectiveness of a technology on a waste can save significant time and money later in the process. To judge the technical certainty that the remedy will attain the corrective action goal, also consider reviewing case studies where similar technologies have been applied.

It is also important to analyze the time to complete the corrective measure, because it directly impacts the cost of the remedy. It is therefore important to carefully evaluate the long-term costs of the remedial alternatives and the long-term financial condition of the facility. Consider including quality control measures in the implementation schedule to assess the progress of the corrective measure. It is also important to determine the degree to which the remedy complies with all applicable state laws.

The Federal Remediation Technologies Roundtable **<www.frtr.gov>** is at the forefront of the federal government's efforts to promote interagency cooperation to advance the use of innovative remediation technologies. Roundtable member agencies include EPA, the U.S. Department of Defense, the U.S. Department of Energy, and the U.S. Department of Interior. This group has prepared over 209 cost and performance reports that can be accessed through CLU-IN **<clu-in.org/remed1.cfm>**. These reports contained in the "Federal Remediation Technologies Roundtable Case Studies" document results from completed full-scale hazardous waste site remediation projects and several large-scale demonstration projects.

Treatability Studies

The four general types of treatability studies are laboratory-scale, bench-scale, pilot-scale, and field-scale.

- **Laboratory-scale** studies are small scale screening studies that generate qualitative information concerning the general validity of a treatment approach.
- **Bench-scale** studies are intermediate studies conducted in the laboratory. Bench scale studies are intended to answer specific design, operation, and cost questions, and are more detailed than laboratory studies.
- **Pilot-scale** studies are large scale experiments intended to provide quantitative cost and design data. They simulate anticipated full-scale operational configurations as closely as possible.
- **Field-scale** studies are large scale studies intended to monitor the performance of treatment systems under real world conditions at close to full scale operations.

More information on treatability studies can be found in *A Guide for Conducting Treatability Studies Under CERCLA* (U.S. EPA, 1992a).

They are meant to serve as primary reference sources, and they contain information on site background and setting, contaminants and media treated, technology, cost and performance, and points of contact for the technology application.

EPA has also prepared an overview of ground-water cleanup at 28 sites entitled *Groundwater Cleanup: Overview of Operating Experience at 28 Sites* (U.S. EPA, 1999a) that is also available from CLU-IN. This overview presents a range of the types of cleanups typically performed at sites with contaminated ground water and summarizes information about the remediation systems at the 28 sites. Summarized information includes design, operation, and performance of the systems; capital, operating, and unit costs of the systems; and factors that potentially affect the cost and performance of the systems.

EPA's TIO Web site **<www.epa.gov/tio>** provides additional information about site characterization and treatment technologies for remediation. This Web site offers technology selection tools and describes programs, organizations, and available publications. Some of the available publications include *Abstracts of Remediation Case Studies, Volumes 1-4* (U.S. EPA, 2000a) which summarize 218 case studies of site remediation prepared by federal agencies. Many of these publications and links are also available through CLU-IN.

4. Evaluating the Effectiveness of Reducing or Eliminating the Source of Contamination

There are two major components of source control that should be evaluated. First, if source control consists of the removal, redisposal, or treatment of wastes, the volume of wastes and residual materials should be quantified and the potential to cause further contamination evaluated. Second, engineering controls intended to upgrade or repair deficient conditions at a waste management unit should be quantified in terms of anticipated effectiveness according to current and future conditions. This evaluation should determine what is technically and financially practicable. Health considerations and the potential for unacceptable exposure(s) to both workers and the public can affect an evaluation.

5. Evaluating the Ease of Implementation

The ease of implementing the proposed corrective measure will affect its schedule. To evaluate the ease of implementation of a specific corrective measure, it is important to

Selecting a Corrective Action Specialist

Once it has been determined that corrective measures are necessary, you should determine if in-house expertise is adequate or if an outside consultant is necessary.

If a consultant is needed, determine if the prospective consultant has the technical competence to do the work needed. A poor design for a recovery system, unacceptable field procedures, lack of familiarity with state requirements, or an inadequate investigation might unnecessarily cost thousands of dollars and still not complete the cleanup.

Some of the most important information to consider in selecting a consultant is whether the consultant has experience performing site investigations and remediations at similar sites, is familiar with state regulations, has staff trained in the use of field screening instruments, has experience in monitoring well design and installations, has established quality assurance and quality control procedures, and can provide references.

consider the availability of technical expertise and equipment, the ability to properly manage, dispose, or treat wastes generated by the corrective measure, and the likelihood of obtaining local permits and public acceptance for the remedy. Consider also the potential for contamination to transfer from one media to another as part of the overall feasibility of the remedy. Cross-media impacts should be addressed as part of the implementation phase. Develop a corrective-measure schedule identifying the beginning and end periods of the permitting, construction, treatment, and source control measures.

6. Measuring the Degree to Which Community Concerns are Met

Prior to selecting the corrective measure(s), you should hold a public meeting to discuss the results of the corrective action assessment and to identify proposed remedies. Consider notifying adjacent property owners via mail of any identified contamination and proposed remedies. You also should identify any public concerns that have been expressed, via written public comments or from public meetings, about the facility's contamination and should address these concerns by the corrective measures being evaluated. The best remedy selected and implemented will be the one that is agreed upon by the state or local regulatory agency, the public, and the facility owner. Review Chapter 1–Understanding Risk and Building Partnerships before selecting any final remedies.

Citizen Guides to Treatment Technologies

EPA's Technology Innovation Office has developed a series of fact sheets that explain, in basic terms, the operation and application of innovative treatment technologies for remediating sites. The fact sheets address issues associated with innovative treatment technologies as a whole, bioremediation, chemical dehalogenation, in situ soil flushing, natural attenuation, phytoremediation, soil vapor extraction and air sparging, soil washing, solvent extraction, thermal desorption, and the use of treatment walls. English and Spanish versions of these fact sheets can be downloaded from CLU-IN **<clu-in.org/remed1.cfm>**.

E. Implementing Corrective Measures

The implementation of corrective measures encompasses all activities necessary to initiate and continue remediation. During the evaluation and assessment of the nature and extent of the contamination, you should decide whether no further assessment is necessary, whether institutional controls are necessary to protect human health and the environment, whether monitoring and site maintenance are necessary, and whether no further action and closure are appropriate for the unit.

1. Institutional Controls

Institutional controls are those controls that can be utilized by responsible parties and regulatory agencies in remedial programs where, as part of the program, certain levels of contamination will remain on site in the soil or ground water. Institutional controls can also be considered in situations where there is an immediate threat to human health. Institutional controls can vary in both form and content. Agencies and landowners can invoke various authorities and enforcement mechanisms, both public and private, to implement one or more of the controls. A state could adopt a statutory mandate, for example, requiring the use of deed restrictions as a way of enforcing use restrictions and posting signs. Commonly used institutional controls include deed restrictions, use restrictions, access controls, notices, registry act requirements, transfer act requirements, and contractual obligations. Additional information on institutional controls is available at EPA's Office of Solid Waste and Emergency Response Web site at <**www.epa.gov/oerrpage/superfund/action/postconstruction/ic.htm**>.

- **Deed restrictions.** These restrictions, also called restrictive covenants, place limits on the use and conveyance of land. They inform prospective owners/tenants of the environmental status of the property and ensure long-term compliance with the institutional controls. Typically, there are four requirements for a promise in a deed restriction: the conveyance of land must be documented in writing; it should precisely reflect the parties' intentions with respect to the scope and duration of the restrictions; there should be "privity of estate" so that it can be enforced by states; and the promise "touches and concerns the land."

- **Use restrictions.** Use restrictions are usually the heart of what is in a deed restriction. Use restrictions describe appropriate and inappropriate uses of the property, in an effort to perpetuate the benefits of the remedial action and ensure property use that is consistent with the applicable cleanup standard. Such techniques also prohibit any person from making use of the site in a manner that creates an unacceptable risk of human or environmental exposure to the residual contamination. Use restrictions address uses that might disturb a containment cap or any unremediated soils under the surface or below a building. A prohibition on drinking onsite or offsite ground water might also be appropriate. Well restriction areas can be a form of institutional control by providing notice of the existence of contaminants in ground water and by prohibiting or conditioning the placement and use of any or all wells within an area.

- **Access controls.** Access to any particular site can be controlled by either fencing and gates, security, or posting or warnings. A state might use the following criteria to determine the appropriate level and means of access control: whether the site is located in a residential or mixed-use neighborhood; proximity to sensitive land-use areas including day care centers, playgrounds, and schools; and whether the site is frequently traversed by neighbors.

- **Notices.** Controls of this type generally provide notice of specific location of contamination on site and disclose any restrictions on access, use, and development of part or all of the contaminated site to preserve the integrity of the remedial action. Types of notices include record notice (notices on land records), actual notice (direct notice of environmental information to other parties to a land transaction), and notice to government authorities.

- **Registry act requirements.** Some states have registry act programs that provide for the maintenance of a registry of hazardous waste disposal sites and the restriction of the use and transfer of listed sites. When a site appears on the registry, the owner must comply with regulatory requirements in regard to use and transfer of the site. The use of a site listed on the registry can not be changed without permission from the state agency.

- **Transfer act requirements.** Some states have transfer act programs that require full evaluation of all environmental issues before or after the transfer occurs. It might be that, within such a program, institutional controls can be established by way of consent order, administrative order, or some other technique that establishes implementation and continued responsibility for institutional controls. A typical transfer act imposes obligations and confers rights on parties to a land transaction arising out of the environmental status of the property to be conveyed. Transfer acts impose information obligations on the seller or lessor of a property. That party must disclose general information about strict liability for clean-up costs as well as property-specific information, such as the presence of hazardous substances, permitting requirements and status, releases, and enforcement actions and variances.
- **Contractual obligations.** One system for ensuring future restrictions on the use of a site, or the obligation to remediate a site, is to require private parties to restrict use by contract. While this method is often negotiated among private parties, it is difficult, if not impossible, to institutionalize control over the process without interfering with the abilities and rights of private parties to freely negotiate these liabilities. Another avenue is for the landowner or responsible party to obligate itself to the state by contract. The state might require a contractual commitment from the party to provide long-term monitoring of the site, use restrictions, and the means of continued funding for remediation.

2. Monitoring and Site Maintenance

In many cases, monitoring might need to be conducted to demonstrate the effectiveness of the implemented corrective measures. Consult with your state to determine the amount of time that monitoring should be conducted. Some corrective measures, such as capping, hydraulic control, and other physical barriers, can require long-term maintenance to ensure integrity and continued performance. Upon completion and verification of cleanup goals, reinstitute your original or modified ground-water monitoring program if the unit is still in active use.

3. No Further Action and Site Closure

When the corrective action goals have been achieved, and monitoring and site maintenance are no longer necessary to ensure that this condition persists, reinstitute your original or modified ground-water monitoring program if the unit is still in active use. It might be necessary, however, to ensure that any selected institutional controls remain in place. Refer to Chapter 11–Performing Closure and Post-Closure Care for additional information on site closures.

Taking Corrective Action Activity List

Consider the following when developing a corrective action program for industrial waste management units:

- ❑ Locate the source(s) of the release(s) of contaminants and determine the extent of the contamination.
- ❑ Consult with the state, community representatives, and qualified remedial experts when developing a corrective action program.
- ❑ Identify and evaluate all potential corrective measures including interim measures.
- ❑ Select and implement corrective measures based on the effectiveness and protectiveness of the remedy, the ease of implementing the remedy, and the degree that the remedy meets local community concerns and all applicable state laws.
- ❑ Design a program to monitor the maintenance and performance of corrective measures to ensure that human health and the environment are being protected.

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